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What’s new in cover crop research in Iowa from 2013 to 2018

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WHAT'S NEW IN COVER CROP RESEARCH IN IOWA FROM 2013 TO 2018

by

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CHAPTER 1

INTRODUCTION

Cover crops are often touted as providing a vast array of benefits for agronomic systems from improving soil quality (Bonner et al., 2014; Moore et al., 2014; Blanco-Canqui et al., 2015; Nair et al., 2015; Nair and Lawson 2015; Panjota et al., 2015; Patel et al., 2015; Woli et al., 2016; Licht et al., 2016; Meng et al., 2016; Appelgate et al., 2017), to improving soil moisture and water holding capacity (Al-Kaisi et al.¸ 2013; Daigh et al., 2014a, 2014b; Basche et al., 2016a, 2016b; Basche and Edelson, 2017), to contributing to weed suppression (Carlisle, 2016; Jokela and Nair, 2016; CTIC, 2017; Schenck et al., 2017), to minimizing nutrient loss either by reducing soil loss due to wind or water erosion, or reducing volatization of nitrous oxide (N_2O) or leaching into groundwater and watersheds (Mitchell et al., 2013; Kladivko et al., 2014; Pederson et al., 2014; Blanco-Canqui et al., 2015; Patel et al., 2015; Tomer et al., 2015; Licht et al., 2016; Parkin et al., 2016; Pederson et al., 2016; Christianson et al., 2018; Martinez-Feria et al., 2018). Cover crops are also a means for farmers to implement sustainable conservation practices with minimal impact on profitability of the operation (Christianson et al., 2018). Of the practices promoted by the Iowa Nutrient Reduction Strategy (INRS), cover crops are one of the cornerstone recommendations which potentially can reduce nutrient loads to the Mississippi River by approximately 30% each for both nitrogen (N) and phosphorus (P) without requiring the farmer to consider expensive practices which may reduce the available arable acres either in short term (e.g. bioreactors) or in the long term (e.g. grassed waterways, prairie strips or wetlands) (Table 1; Lawrence, 2017). Blanco-Canqui et al. (2015) also suggested the addition of cover crops will provide an opportunity for farmers to gain more benefit from their operation with minimal changes to their management practices.

Table 1: Potential nutrient loss reduction by practice

Practice[a]	Potential N Loss Reduction (%)	Potential P Loss Reduction (%)
Cover crops	31	29
Buffer strips		58
Conservation tillage		33
No tillage		90
Nutrient application rate	10	17
P placement		36
Nitrification inhibitor	9	
Terraces		77
Ponds and sediment basins		85
Bioreactors	43	
Wetlands	52	
Drainage water management	33	

[a]Lawrence, 2017

Adding cover crops to an agronomic system is not without challenges and financial risks. As with the cash crop, weather can impact the available planting window for seeding the cover crop and when the farmer can access the field to terminate the cover crop (CTIC, 2017). Lack of available cover crop planting equipment, seed sources, and service providers are other challenges cited by the farmers. Farmers are concerned about the additional time and labor which may be required to manage the cover crop (CTIC, 2017). Farmers also find determining the appropriate amount and timing of N applications can be more challenging when cover crops are a part their management system (Basche et al., 2016b). While some cover crops seem to have allelopathic impacts on weeds, farmers are concerned cover crops also may have the same impact on the cash crop (Bakker et al., 2016) or develop into a weed problem (CTIC, 2017). Even with the challenges, surveys repeatedly show there is increasing interest in learning from experienced cover crop practitioners as well as the scientific community on how to best incorporate cover crops into their management practices (CTIC, 2017). The objective of this project is to provide an extensive literature review of cover crop publications written by Iowa (IA) researchers and from publications of cover crop research performed in IA from 2013 to 2018. In addition, this paper summarizes research opportunities identified in the literature as well additional research possibilities from gaps identified during the course of this review.

Overview of the Role of Cover Crops in the Iowa Nutrient Reduction Strategy

The INRS was released in 2013 to meet the requirements of 2008 Gulf Hypoxia Action Plan which required states along the Mississippi River watershed to reduce nutrient loading for both N and P by 45% by 2015 (US EPA, 2008). The Gulf Hypoxia Action Plan required each state to provide a nutrient reduction strategy no later than 2013 in the hopes individual states would be well on their way to implementing their programs (US EPA, 2008). The INRS is a science and technology-based framework to assess and reduce nutrient loads to IA waters and to the Gulf of Mexico and represents the results of a collaboration between Iowa State University (ISU) College of Agriculture and Life Sciences, Iowa Department of Agriculture and Land Stewardship (IDALS), Iowa Department of Natural Resources (DNR), United States Department of Agriculture-Agricultural Research Service (USDA-ARS), USDA Natural Resources Conservation Service (USDA-NRCS), the Environmental Protection Agency (EPA,) as well as representatives from University of Illinois and University of Minnesota (Lawrence, 2012). The INRS, which took two years to develop, encompasses both point sources which include industrial, commercial and municipal entities as well as non-point sources which include agriculture. For agriculture, INRS outlines what is described as 'targeted practices' based on the best currently available-technologies (Lawrence, 2012). The task force focused on nitrate (NO_3) and P loss. Iowa, which is considered a significant contributor to the hypoxia problem in the Gulf, is estimated to account for between 10 and 17% of the NO_3 load and between 5 and 10% of the P load (Lawrence, 2014b). Iowa contributes an average of 29, 45, and 55% of the NO_3 load to three of the main watersheds which feed into the Gulf of Mexico: Mississippi-Atchafalaya Basin, Upper Mississippi River Basin, and Missouri River Basin, respectively (Jones et al., 2018). The INRS key components outline the goals identified to reach the objective as defined by the Gulf Hypoxia Action Plan and include establishment of baseline conditions, performance of literature reviews, and estimation of potential reduction and implementation costs. The first goal was necessary to measure progress toward the target N and P reduction. The second was identified in order to take advantage of scientific knowledge available on current and future technologies to improve nutrient management (Lawrence, 2012).

In addition to the stated INRS objectives, additional action items included prioritization for watershed improvement projects, support for on-going research, and improvements in outreach, education and cross-state collaboration, increased recognition, and establishment of metrics to track progress (Lawrence, 2012). Watershed improvement projects started with 13 watersheds and expanded to 16 in 2015 (IDALS, 2016). These watershed projects are intended to show the 'effectiveness and adaptability' of the recommended practices on a smaller scale and are funded not only through the state under the Iowa Water Quality Initiative but also from partners and landowners (IDALS, 2016). One of the outcomes of INRS was the formation in 2014 of the Iowa Nutrient Research and Education Council. This organization focuses on providing instruction and materials to the state's Certified Crop Advisors (CCA) and agriculture retailers so they in turn can further educate their farmer partners and encourage the use of the recommended best practices. Along with the CCA and agriculture retailers, the council also brought together farm and commodity organizations and crop production groups (IDALS, 2016). Voluntary participation is one of the key recommendations from INRS and did include example cost implication estimates for the farmer (Lawrence, 2012). Recognizing individual farmers is an integral part of INRS and requires identifying, rewarding and publicizing successful implementation of the recommended practices and proven reduction of nutrients into the farmer's local waterways (IDALS, 2016).

The task force recommended the voluntary approach in hopes of reducing the risk of EPA implementing regulations like was done for the Chesapeake Bay Area (Lawrence, 2014a). Critics, however, say without regulations and accompanying fines farmers will continue to over apply synthetic fertilizer and manure. These critics include both environmental groups and the former Des Moines Water Works director who initiated a lawsuit against three northern IA counties claiming their tile drainage systems were losing excessive NO_3 into the Raccoon River, Des Moines watersheds (Eller, 2016). In response to the criticism, state officials claim regulations will stifle innovation and slow investment into ongoing research and development (Swoboda, 2013). The greater challenge is ensuring funding is available for farmers to invest in the long-term improvements to achieve the overall NO_3 and P reduction targets (Steimel, 2016).

Task Force Recommendations for Managing Nitrogen and Phosphorus

The task force is counting on innovation by the farmer to implement the 4R principles identified in the Gulf Hypoxia Action Plan's 2013 reassessment: Right amount, Right source, Right placement, Right timing (US EPA, 2013). The task force initially recommended the use of N inhibitors for fall applied anhydrous ammonia estimating the increased cost of using the inhibitor would be offset by the increased yield (estimated at 6 bu/ac increase in yield) as well as side-dressing and applying N fertilizer during N uptake periods and periodic soil sampling and/or 'crop canopy sensing' (Lawrence, 2014a). However, in the annual progress report published December 2017, the use of inhibitors with spring applied anhydrous ammonia, fall applied manure and spring applied urea, urea-ammonium nitrate (UAN) and manure is no longer recommended due to insufficient data to support the inhibitors contribution to reducing N loss (IDALS et al., 2017). Recommendations to reduce P loading in the Mississippi watershed included applying P fertilizers only if soil test P levels are at optimum or no greater than the manure management plan P Index, utilizing organic manure sources however ensuring minimal runoff could occur, incorporating non-organic sources, as well as the use of cover crops (Lawrence, 2014a). Additionally, widespread adoption of cover crops is projected to reduce nutrient loads by 29%.

Cover crop adoption started increasing in IA in 2011 and has grown from an estimated 15,000 acres to over 875,000 acres in 2018 (Iowa Learning Farms, 2019). However, to meet the reduction goals for the INRS, cover crop adoption in IA needs to increase to 10 to 14 million acres (IDALS et al., 2017). Assuming cover crops are the one nutrient reduction practice that a farmer could implement with the least loss of arable acres with minimal reduction in overall cash crop yields, reaching nutrient reduction goal determined for Iowa at the current adoption rate will require almost 100 years. The goal of this literature review is to develop an understanding of cover crop research in IA from 2013 through 2018 and to determine if current research can help improve cover crop adoption rates by IA farmers. Numerous studies addressed cover crops impact on soil quality, water quality and nitrous oxide emissions, addressed the use of modeling to estimate cover crops effects on nutrient losses, and addressed current farmer views regarding opportunities and challenges including cover crop in their management systems.

CHAPTER 2

COVER CROP IMPACT ON SOIL QUALITY, WATER QUALITY AND NITROUS OXIDE EMISSIONS

Evaluating Cover Crop Impact on Soil Quality

Cover crops are frequently promoted for their abilities to improve soil properties by reducing compaction, improving hydraulic characteristics, moderating soil temperatures, and improving the soil microbiological environment (Blanco-Canqui et al., 2015). According to Moore et al. (2014) soil organic matter is a key contributor to overall soil quality through its ability to facilitate aggregate formation, to serve as a plant-available N source, and its water-holding capacity. In their study, Moore et al. (2014) evaluated soil organic matter, particulate organic matter, and mineralizable N in a no-tillage corn-corn silage-soybean (*Glycine max* (L.) Merr.) rotation both with and without cereal rye (*Secale cereale* L.) cover crops. Particulate organic matter worked well as a soil organic matter/quality indicator as it is sensitive to different management practices; mineralizable-N is one of the more common indicators used for soil quality assessments (Moore et al., 2014). Data were collected over a nine-year period from field trials performed at ISU Boone County farm. At the 0 to 5 cm soil depth, rye after corn silage and after corn had an average 15% more soil organic matter than the same treatments without cover crops. The impact was less noticeable after soybean (Moore et al., 2014).

The soil quality benefits from cover crops were magnified during the 2012 growing season drought conditions in IA (Al-Kaisi et al., 2013; Daigh et al., 2014a). Deterioration in soil characteristics due to crusting, loss of soil structure and aggregation were exacerbated by lack of snow and/or residue cover the previous winter (Al-Kaisi et al., 2013). The researchers noted soils with higher levels of organic matter and water holding capacities provided a better growing environment for the cash crops compared to soils with poorer soil quality which were stressed due to drought conditions (Al-Kaisi et al., 2013; Daigh et al., 2014a). Cover crops used for soil management under dry conditions were identified by Al-Kaisi et al. (2013) as a means to protect the soil from water erosion, improve or at very least maintain the soil structure, increase organic matter and scavenge nutrients. However, they noted establishing a suitable stand is challenging in dry soil conditions. The mulching effects of cover crops and their residues can also help conserve soil water (Daigh et al., 2014a). Basche and Edelson (2017) further proposed cover crops as well as other perennial crops can help farming operations minimize the impacts of increasing frequency and extreme nature of weather events (i.e. drought, flooding, catastrophic rainfalls, etc.). In another study delving further into the effects of long-term cover crop usage in a corn/soybean rotation, Basche et al. (2016b) collected soil water measurements during the period approximately ten days before and after cover crop termination and during peak cash crop demand at reproductive growth when cover crop soil water usage could impact crop yield. The data, which were collected between 2008 and 2014 from the corn-soybean no-tillage and corn-soybean-winter rye cover crop rotations at ISU Boone County research farm, confirmed cover crops are likely not detrimental to soil water availability to the cash crops based on measurements of cash crop biomass, leaf area and yield, thus potentially eliminating one negative cover crop perception (Basche et al., 2016b).

On the other hand, cover crops, specifically winter rye which is the most commonly used cover crop in the Upper Midwest due to its winter hardiness (Appelgate et al., 2015; Basche et al., 2016a; Acharya et al., 2017; Schenck et al., 2017), may immobilize soil NO_3-N rendering it unavailable to the following cash crop (Patel et al., 2015; Panjota et al., 2016). Because a majority of N and C are taken up by the shoots resulting in a higher C:N ratio in the roots, soil N or N from the degrading cover crop shoots is potentially immobilized and not available (Patel et al, 2015). Panjota et al. (2016) found with the same rotations, i.e. winter rye following corn and winter rye following soybean, the cover crop did not serve as a reliable source of plant-available N. Both studies identified the need to develop cover crop best management practices if improved nutrient availability is anticipated from the addition of cover crops to a farm operation. Woli et al. (2016) also concluded the addition of a winter rye cover crop did not increase plant available N to the subsequent cash crop. It is noted, however, cover crop potential contribution to soil N is also dependent upon growing conditions and soil fertility (Nair and Lawson, 2015). The contribution can be further enhanced with cover crops such as clovers if inoculated with soil bacterium such as *Rhizobium sp.* (Nair et al., 2015). In a study to determine the effects different biofuel cropping systems have on N mineralization, Meng et al. (2016) evaluated a range of residue covers generated from N-fertilized prairie to continuous corn with and without a winter rye cover crop to a standard corn-soybean rotation as well as a perennial prairie in one of ISU Boone County test sites. Results documented the greatest N mineralization rates occurred with N-fertilized prairie followed by the continuous corn with cover crop. Meng et al. (2016) concluded cropping system had a significant impact on the N mineralization rate most likely due to the differences in soil residual N concentration.

Evaluating Cover Crop Impact on Water Quality

Cover crops are considered a practical (Christianson et al., 2017) and effective means to minimize nutrient loss in water quality through their ability to reduce NO_3-N leaching and both wind and water erosion (Daigh et al., 2014a; Pederson et al., 2014; Blanco-Canqui et al., 2015; Nair and Lawson, 2015; Meng et al, 2016; Pederson et al., 2016). Blanco-Canqui et al. (2015) summarized the ability of cover crops to scavenge and retain nutrients in the root zone as one of their more important benefits. Cover crop scavenging converts nutrients to forms which are less prone to leaching and through their decomposition after termination, gradually releasing the nutrients back into the soil. Blanco-Canqui et al. (2015) repeated the importance of cover crops as both wind and water erosion control solutions for the period between harvest and planting when fields have the least ground cover. Blanco-Canqui et al. (2015) also stated cover crops also may serve to minimize nutrient losses when organic fertilizers are applied across the fields.

Pederson et al. (2014; 2016) described the impact of cover crops on NO_3-N concentration in tile drainage water. Data were collected from the six treatments at ISU Northeast Research Farm in Nashua, IA:

- Treatment 1: corn-soybean, conventional tillage, spring UAN;
- Treatment 2: corn-soybean, conventional tillage, fall manure corn only;
- Treatment 3: corn-soybean, conventional tillage, fall manure both corn and soybean;
- Treatment 4.1: continuous corn, conventional tillage, fall manure;
- Treatment 4.2: continuous corn, conventional tillage, fall manure with stover removal;

- Treatment 5: corn-soybean with rye cover crop after each, no-tillage, spring UAN;
- Treatment 6: corn-soybean, no-tillage, fall manure.

The treatments were established in 2007; data for the groundwater quality assessment were collected from 2008 to 2012 (Pederson et al., 2014) and from 2008 to 2015 for the drainage water evaluation (Pederson et al., 2016). The cover crop treatment provided the greatest reduction in NO_3-N loss across all the treatments. On average, the loss was 45% less compared to the five-year average NO_3-N concentration from drainage samples collected from fall manure (treatment 6) and 31% less compared to the conventional tilled with spring fertilization (treatment 1) drainage samples (Pederson et al., 2014). Compared to the conventional tillage fall manure treatment drainage samples (treatments 1 through 4), the NO_3-N concentrations in samples collected from the cover crop (treatment 5) field drainage were at least 50% less (Pederson et al., 2014). For the eight-year period, overall average NO_3-N concentration in drainage water for the cover crop ranged from 30% less compared to conventional tillage with spring fertilizer (treatment 6) to 56% less compared to conventional tillage, fall manure (treatment 2) (Pederson et al., 2016). Overall average yields, however, were 8.8% to 13.2 % less for both corn (treatments 1, 2, and 3) and 7.4% to 17.0% soybean (treatments 1, 2, 3, and 6) between the cover crops and no-tillage compared to the conventional tillage treatments (Pederson et al., 2016). Unfortunately, this long-term study did not include a corn-cover crop-soybean-cover crop rotation with fall or spring manure application to determine how a cover crop could reduce NO_3-N concentrations in drainage water under these conditions. Water quality impacts may also come from reduced flow rates through field artificial drainage systems. In a study to understand the impact of different crop rotations on soil water hydrology, Daigh et al. (2014b) noted reductions in peak flows from 23% to 36% from subsurface drainage where winter rye cover crops were utilized compared to corn rotations with no cover crops and were similar to results seen from fields planted into a reconstructed prairie.

Evaluating Cover Crop Impact on Nitrous Oxide Emissions

Although not normally considered a nutrient loss, agriculture soil management practices are the most significant source of the greenhouse gas N_2O (US EPA, 2018). According to the U.S. EPA, N_2O is 300 times more powerful at trapping heat in the atmosphere compared to carbon dioxide (Basche et al., 2014; US EPA, 2018). Soil management practices accounted for 76.7% of N_2O emissions in 2016 (US EPA, 2018) versus 69% in 2013 (Basche et al., 2014). More importantly, N_2O emissions from agricultural practices were 13.2% greater in 2016 compared to 1990 even with year to year variations (US EPA, 2018). Determining the net effect of cover crop potential to reduce N_2O emissions has proven challenging. This is due to the complexity of the N cycle as well as the interaction between cover crops and N_2O emission levels with other management practices (Basche et al., 2014; Mitchell et al., 2013). Mitchell et al. (2013) noted carbon (C) availability, specifically mineralized C to which cover crop residues contribute, influenced N_2O emissions. In a winter rye before corn study, Mitchell et al. (2013) evaluated N_2O emissions and NO_3-N concentrations at three banded N fertilizer rates (0, 135, and 225 kg N ha^{-1}) in the field and with laboratory assays from samples collected from the fertilizer bands. In every fertilizer treatment, cover crops decreased soil NO_3-N concentrations both in the field and laboratory assays. In the field, N_2O emissions were decreased with no fertilizer application, were increased at the middle N fertilizer rate and were variable at the high fertilizer rate. Nitrous oxide emissions were greater in field samples with no fertilizer applications but not in field samples from the banded N fertilizer applications. Glucose addition to laboratory samples increased N_2O emissions across all three fertilizer rates indicating that C availability has a significant role in these emissions (Mitchell et al., 2013). Using the data collected from the same study, Iqbal et al. (2015) also concluded cover crops did not consistently reduce N_2O emissions nor did the study provide insight into cover crop best management practices which would contribute to reduce emissions.

In a meta-analysis, Basche et al. (2014) analyzed the ratio of the natural log of N_2O flux with a cover crop compared to systems without a cover crop (LRR) from 106 observations in twenty-six peer reviewed articles. The analyses identified 40% of cover crop treatments had a negative LRR, i.e. N_2O emissions decreased with the cover crop and 60% had a positive LRR or increased N_2O emissions with cover crops. Conditions identified by the Basche et al. (2014) as having positive LRRs included higher LRRs at lower N rates for legume versus non-legume species, higher LRRs when cover crop residues were incorporated versus not incorporating, higher LRRs in areas with higher total precipitation and more variable precipitation rates, and higher LRRs during cover crop decomposition than during cover crop growth. Results of N_2O emission measurements from treatments with cover crops over an entire year found periods of higher N_2O emission were offset by periods of lower N_2O emission (Basche et al., 2014). Basche et al. (2014) emphasized cover crops take up N which could be lost to leaching or in the case of a legume cover crop, fix N and therefore do impact N_2O emissions, albeit indirectly.

Parkin et al. (2016) recognized the need for a long-term study of the impact of cover crops in a corn-soybean rotation with and without a cereal cover crop, winter rye. The no-tillage field study was performed over a 10-year period near Boone, IA. Both N_2O emissions and NO_3-N leaching losses were measured during the period with the latter used to estimate indirect N_2O emissions. In this study, Parkin et al. (2016) found the total direct emissions between cover crop and no cover crop were not significantly different but the cover crop impact on indirect emissions was significant compared to no cover crop over the ten-year period. As with the one-year period studied in the meta-analysis, there was no significant difference between cover crop and no cover crop treatments for the 10-year cumulative total N_2O emissions. Parkin et al. (2016) concluded the difference in indirect emissions was most likely due to reduced NO_3-N leaching losses with a cover crop in the system.

Precipitation (Parkin et al., 2016), N fertilization rates (Mitchell et al., 2013; Iqbal et al., 2015), tillage systems and residue management (Basche et al., 2014; Iqbal et al., 2015), legume versus a non-legume species (Basche et al., 2014), and available mineralizable C (Mitchell et al., 2013; Iqbal et al., 2015) all influence cover crop N_2O emissions. Widespread cover crop adoption, while important for nutrient load reduction through their ability to mitigate NO_3-N leaching losses, may not play a significant role in reducing the contribution from agriculture to greenhouse N_2O gas emissions.

CHAPTER 3

ESTIMATING COVER CROP IMPACTS ON NUTRIENT LOSS THROUGH MODELING

Benefits from adding cover crops to row-cropping systems are predicted based on modeling tools such as Agricultural Production Systems sIMulator (APSIM) or Root Zone Water Quality Model (RZWQM). In recent publications, researchers used these tools

- to develop a N use efficiency (NUE) tool for both the cropping system NUE and soil environment NUE (Martinez-Feria et al., 2018),
- to predict reductions in soil C loss, erosion, NO_3 leaching and N_2O emissions over a 45-year simulation period (Malone et al., 2014; Basche et al., 2016b),
- to estimate NO_3 losses to subsurface drain flow and/or N_2O emissions over a twelve year period (Gillette et al., 2018),
- to analyze potential revenue from harvesting winter rye cover crops (Malone et al., 2018), and
- to evaluate a rye cover crops effects on corn yield (Martinez-Feria et al., 2016a).

Teshager et al. (2017) used the Soil and Water Assessment Tool (SWAT) to evaluate the potential impact of various best management practices on nutrient loss in the Raccoon River watershed in IA. In addition, several studies evaluated the effectiveness of different modeling tools, Root Zone Water Quality Model (RZWQM), HERMES, and DRAINMOD-N II in predicting NO_3 loss in subsurface drainage compared to field data (Malone et al., 2017; Xuan D et al., 2017).

Martinez-Feria et al. (2018) recognized the current NUE evaluation methods were either focused on N cycling in terms of the crop (NUE_{crop}) or N cycling in terms of the soil (NUE_{soil}). Crop N cycling is focused on maximizing yields with the least amount of inputs, i.e. the ratio of crop yields to N inputs; NUE_{soil} is focused on how much N is lost and how much N is added to a system. The crop-focused efficiency value does not account for environmental influences on N losses or storage in the soil; the soil focused efficiency value does not account for crop productivity. To overcome the limitations of the separate NUE values, Martinez-Feria et al. (2018) developed a system NUE (sNUE) which is the ratio of NUE_{soil} to NUE_{crop}. They verified its effectiveness as an assessment tool in APSIM utilizing data collected from field sites near Kelley and Nashua, IA. One of the long-term scenarios included a rye cover crop between corn and soybean. The model showed adding cover crops to the system improved the soil capacity for storing N by better residue management. Adding the rye cover crop did not affect NUE_{crop} which is not unexpected, but did increase the NUE_{soil} and therefore sNUE, indicating the cropping system is potentially more efficient with a cover crop. Basche et al. (2016a) also used APSIM to evaluate the potential benefits a cover crop could provide in response to increasing frequency of extreme weather events (both precipitation and drought) with climate change. They compared data collected from a long-term corn-soybean rotation with and without cover crop trial located in Boone County, IA. For this study, only the no-tillage corn-soybean and no-tillage corn-soybean-winter rye cover crop rotation data were used for the analyses. Similar to the field research studies, the modeling scenarios predicted extended use of cover crops would have little to no effect on crop yields, potentially reduce erosion, mitigate but not completely offset the predicted soil C loss, and could provide a buffer to climate change impacts on the cash crops.

The simulations, when combined with the Global Climate Change model, also predicted cover crops will decrease N_2O emissions in the long term (Basche et al., 2016a).

Similar to Basche et al. (2016a), Malone et al. (2014) also predicted annual NO_3-N loss across the Midwest for no-tillage corn-soybean systems. Cover crop trials near Boone, IA as well as C/N cycling data collected from a field study near Story City, IA were used to validate the RZWQM for the purposes of this study (Malone et al., 2014). Simulation results predicted overall NO_3-N loss through drainage systems could be reduced as much as 42% across the Midwest. Seeding date determined how effective the cover crop was in terms of reducing NO_3-N loss most likely due to air temperatures and the lack of time for the crop to achieve effective biomass if planted later in the fall. Malone et al. (2014) did acknowledge the simulation limitations which included utilization of only one cover crop species, assumption of one soil type across the entire region, lack of alternative cash cropping systems, exclusion of areas without artificial drainage or a cover crop's impact on potential soil losses due to erosion. The RZWQM simulation tool was also used by Gillette et al. (2018) for analyses of cover crop impact on NO_3-N losses through field artificial drainage system and N_2O emissions from the nine-year field study also conducted in Boone County, IA. For this field site, the simulation predicted a 54% reduction in NO_3-N concentration compared to the actual 60% reduction when comparing the rotation with cover crop to the rotation without cover crop (Gillette et al., 2018). Using data from central IA, Malone et al. (2018) evaluated additional scenarios to determine if harvesting an unfertilized winter rye cover crop in mid-May or if fertilizing the winter rye cover crop in early April and harvesting in early May prior to planting corn impacted NO_3-N losses. Conservative estimates for fertilizer costs and price received for the harvested cover crop plus estimates for energy costs were used to determine the potential revenue. For the nine-year period, the model predicted the no-fertilizer/mid-May cover crop rotation NO_3-N concentration in the drainage system was 44% less than with the same rotations without cover crop. The fertilized cover crop resulted in NO_3-N loss reduction of 54% compared to no cover crop rotations and an 18% NO_3-N loss reduction for the rotations with the non-fertilized cover crop. The simulation also predicted revenue and net energy would be positive from the higher biomass harvested from the fertilized cover crop. However, studies in the field are needed to verify the results of the simulation analyses.

Martinez-Feria et al., (2016a) compared six years of data collected from a no-tillage continuous corn with and without cover crop field trial located near Boone, IA with fertilization rates based on the late spring soil NO_3 test. Data from the trial and from a literature review were utilized to determine if there were relationships between cover crop biomass and corn yields, drainage water volume, NO_3-N losses, and soil temperature and seedling emergence. Weather data from 1985 to 2014 with mid- or late- April or May cover crop termination were entered into APSIM to estimate long-term impacts of cover crops for the same criteria. Field trial data showed corn yields were on average 6% less with cover crop compared to no cover crop; APSIM results indicated cover crops in the long term have minimal corn yield impact. The cover crop did compete for soil water but this impact only occurred during spring seasons with much less than normal precipitation (Martinez-Feria et al., 2016a). As with other studies (Iqbal et al., 2015), corn with cover crop did reduce NO_3-N in drainage water by reducing NO_3-N concentration. Finally, Martinez-Feria et al. (2016a) found no significant impact of the cover crop on soil temperature suggesting cover crops should have minimal influence on seedling emergence unless there was another abiotic stress. Teshager et al. (2017) expanded the use of simulation models from a field-basis to a watershed, in this case the Raccoon River watershed in west-central IA. The SWAT simulation scenario used cover crops in areas prone to high NO_3-N losses and in areas with row-cropping prone to high total suspended solids in drainage water. In the scenario, pasture land with high total suspended solids in drainage water was converted to perennial grasses. Teshager et al. (2017) did conclude this scenario was not only effective in reducing nutrient loads but also a practical and realistic alternative. This scenario also maintained the original area for row cropping therefore overall had the least adverse impact on production in the watershed area (Teshager et al., 2017). Potential for cover crop adoption to reduce agricultural NO_3-N losses in the Mississippi River Basin and subsequently reduce Gulf of Mexico hypoxia were explored further by Kladivko et al. (2014). Two counties each from Ohio, Indiana, Illinois, IA, and Minnesota were selected for the RZWQM evaluation which included the following assumptions for the scenarios:

- winter cereal rye was the cover crop of choice and adoption was based on previous crop history and estimated residue cover;
- crop rotations were primarily corn-soybean or continuous corn;
- no-tillage and/or ridge tillage were utilized as appropriate in corn-soybean rotations; and
- conventional tillage was used for continuous corn.

Kladivko et al. (2014) estimated between 70 and 80 percent of the cropland in Wright and Calhoun, IA are suitable for cover crops. The current practice of fall-tillage after corn in these counties, however, will limit their adoption (Kladivko et al., 2014). With successful planting of cover crops across the entire five state area, agriculture could reduce nutrient losses to the Mississippi River Basin by 20% (Kladivko et al., 2014).

Yet another tool, the Landscape Environmental Assessment Framework (LEAF), which combined the Revised Universal Soil Loss Equation 2, the Wind Erosion Prediction System and Soil Conditioning Index, was used to identify the best management practices for sustainable cropping systems intended to supply biomass feedstock for biofuel operations (Bonner et al., 2014). Winter rye cover crops for all rotations, management practices, and stover removal schemes were identified as the most sustainable practice for biofuel operations. These models predicted increases in corn stover availability between approximately 25 to 50% depending upon the conservation practices utilized across the areas studied. Bonner et al. (2014), however, emphasized these decisions must be made at the farm operation level rather than county or regional level.

Finally, two IA field studies evaluated the effectiveness of three different modeling tools, DRAINMOD-N II (Xuan et al., 2017), HERMES and RZWQM (Malone et al. 2017) to predict NO_3-N loss in subsurface drainage for a corn-soybean rotation with and without cover crops. Xuan et al. (2017) utilized field data collected from 2005 to 2009 at the Iowa Agricultural Drainage and Water Quality Research and Demonstration Site in Pocahontas County, IA. In addition, Xuan et al. (2017) used DRAINMOD-N II to evaluate the long-term effect of cover crop (20 years) Malone et al. (2017) used data generated between 2002 and 2005 in Boone County, IA. Xuan et al. (2017) concluded, even though DRAINMOD-N II could adequately predict water and N transport in the soil profile, additional research was needed to simulate the full N cycle in the soil. Comparing the simulation effectiveness between RZWQM to HERMES, Malone et al. (2017) identified shortcomings with HERMES including its inability to predict year-to-year NO_3-N concentration variation and differences between cover crop and no cover crop.

The use of models may be worthwhile to help identify good management practices to optimize the potential benefits from cover crops or to formulate policy recommendations. Tomer et al. (2015) have proposed using Arc geographic information system (ArcGIS) mapping tools and their proposed Agricultural Conservation Planning Framework (ACPF) to provide conservation professionals a tool to assist farmers in developing management plans which are predicted to reduce nutrient losses to the local watershed. Source data for the tool were developed from two watersheds, one of which was the Beaver Creek watershed in IA (Tomer et al., 2015). Modeling involved placing in-field and edge-field conservation practices where needed based on field drainage and field geography and randomly distributing cover crops across row cropping areas in each watershed. The goal was to determine the best combination of conservation practices to reach the 40% NO_3-N loss reduction targeted in INRS. Results of this study indicate reaching the goal will come at the loss of ~5% of productive cropland (Tomer et al., 2015). The tool is capable of providing consistent projections across fields, regions and even states and is directed to watershed policy makers and planners. Unfortunately, it is too complex for the individual farmer to utilize without input from a skilled user. Except for Gillette et al. (2018), recent research utilizing and improving models does not provide practical information for addition of cover crops to cropping systems.

CHAPTER 4

COVER CROP ROLE IN FARMER OPERATIONS: PERCEPTIONS, CHALLENGES, PRACTICAL CONSIDERATIONS AND ECONOMICS

Farmer Perceptions and Challenges of Cover Crop Implementation

Research in IA and/or by IA-based individuals including universities, USDA/NRCS, ARS, SARE-CTIC, and non-government organizations have promoted and continue to promote the benefits of cover crops, however, IA farmers are slow to add this management practice to their operations. Researchers have deployed several methods such as in-person surveys, on-line surveys, and interviews with a spectrum of cover crop adopters from those who have no knowledge of cover crops to those who have no interest and/or are resistant to adding cover crops to their management system to the early adopters and ongoing users. Iowa, as well as other states, must bridge the gap between the users and non-users to increase the adoption rate across the state to reach the targeted nutrient reduction goals. Myers and Watts (2015), Arbuckle and Roesch-McNally (2015), Carlisle (2016), Carlson and Stockwell (2016), Dunn et al. (2016), Basche and Roesch-McNally (2017), Gonzalez-Ramirez et al. (2017), SARE-CTIC (2017) and Roesch-McNally (2018) have all attempted to address and improve understanding of the successes and obstacles involved with a farmer continuing to use cover crops or adding cover crops.

Arbuckle and Roesch-McNally (2015) used surveys and interviews with IA farmers focusing on three main areas: perceptions of cover crop practices, factors facilitating the practice, and the role of crop and livestock diversity in cover crop adoption. Those who incorporated cover crops into their management system either in part or across the entire operations felt their fields had reduced soil and nutrient loss and described increased ‘soil productivity.’ Even then, the respondents indicated they wanted increased and ongoing support both knowledge-wise and technology-wise for continuing cover crops as a part of their management strategy. Non-users were concerned about the impact of weather for successful establishment and/or termination of the cover crop due to the short growing season available between cash crops. Non-users were concerned about the lack of knowledge and uncertainty related to cover crop adoption and the potential negative impacts on yield. Uncertainty surrounded the perceived risks from cover crop water use and its impact on cash crop yields, from increased crop insurance complexity, potential negative impact on the following cash crop, or increased expenses without increased profits. Finally, Arbuckle and Roesch-McNally (2015) identified farmers utilizing more diverse crop and livestock management systems were more likely to either incorporate or be open to adding cover crops to their operations.

Basche and Roesch-McNally (2017) used focus groups to further investigate the external influences, i.e. economic stresses and inherent limitations within the most widely utilized corn-soybean rotation management system in IA, impacting cover crop adoption. By its nature, this predominant corn-soybean cropping system is low in diversity. In these focus groups, 26 of the 29 individuals had either planted or continue to incorporate cover crops in their operation. The focus groups identified several research opportunities including the need to place a monetary value on soil resources beyond the field scale. Because there currently is no monetary bonus for fields where farmers have worked to improve soil health or to reduce erosion, development of a ‘soil health index’ similar to the corn suitability index could provide the incentive needed for expansion of soil health practices. Even though cereal rye, due to its cold tolerance and fast germination rate, is well suited to the short growing window for cover crops in the upper

Midwest, the focus groups indicated additional research should include expanded choices for species selection. The focus groups felt current research is performed in 'ideal locations' with their well-characterized soils and flat fields and will not necessarily provide the needed insights into how cover crops will perform across the diverse field topographies and soil types found in IA. They also felt current research focused on single statistically quantifiable causes and effects rather than deploying a whole systems approach. The focus groups recommended research expands to include not only cover crop perceived benefits, but also other components of the management system: fertilizer management, pest management, equipment, tillage practices, etc. In addition, the focus groups recommended identifying technical experts who have successfully adopted cover crops for 'typical' IA or upper Midwest cropping systems.

Carlisle (2016) reviewed the literature to identify what influences farmer adoption of practices aimed at improving soil health. Perceived benefits which could lead to increased cover crop adoption included not only the standard positive impacts of decreased erosion, reduced nutrient loss, and increased cash crop yields but also the potential for cost sharing through incentive programs. Increased adoption also was driven by increased knowledge and experience with cover crops. Detrimental to cover crop adoption were the perceived problems with potential interference with fall harvest and for delays in spring planting, the lack of short season varieties for both the cover crop and the cash crop, and lack of knowledge and equipment for handling the cover crop. Carlisle (2016) noted the perception of interference with planting at cover crop termination and with harvest at cover crop planting was more pronounced with those who had larger operations. As in the previous studies, general benefits which could increase cover crop adoption included soil conservation, potential reduced input costs for the cash crop and increased yields. Confusing regulations, lack of accessibility and affordability of equipment to plant cover crops were also mentioned as possible detriments.

Carlson and Stockwell (2016) identified several of the same opportunities for additional research into more in-depth cost benefits economic analyses for cover crop use over periods ranging from less than three years to six years or more; developing alternative seeding methods including equipment and timing options; long-term effect on cash crop yields; breeding for cover crop and cash crop symbiosis; and optimization of cover crop nutrient delivery or availability for the cash crop. In addition, they recognized additional research is needed to determine the most effective manner of increasing the number of and access to cover crop proponents and technical experts including the use of the agriculture industry to serve as technical resources for the farmer. More research into practical subjects to dispel the perceived risks of cover crop use and long-held 'truths' about what defines an excellent crop operation. Carlson and Stockwell (2016) further suggest the historical benchmark of a 'clean' field is a well-managed field and anything other than the cash crop in a field is a 'weed' requires further research on what it will take to create the needed paradigm shift.

Dunn et al. (2016) utilized the results from the 2014-2015 SARE-CTIC on-line surveys to gather data from early adopters of cover crops, a majority of which continue to use cover crops in their operations, as well as from operations which discontinued cover crop use. Early adopters appeared very flexible, were willing to learn via trial and error and to keep learning. Similar to Carlisle (2016), Dunn et al. (2016) also identified larger operations generally discontinued cover crop use citing the increased complexity they added to their operations and their increased costs. Resources were required to select the cover crop seed, determine timing for planting, and termination of the cover crop and identification of the methods and equipment needed for both.

Farmers who consider cover crops an integral part of their operations have recognized cover crop use is a long-term commitment and it takes several years to learn what works best in their operation. Gonzalez-Ramirez et al. (2017) conducted a survey of 25 IA farmers approximately half of who use cover crops in their operations to understand their decision-making processes and the influence of financial incentives and barriers to adoption. Incentive payments were expected by several of the farmers as long as this conservation practice is voluntary. As expressed in previous studies, concerns were raised regarding potential negative impacts on the cash crop, risks associated with planting and terminating the cover crop and potential delays in cash crop planting due to cover crop termination. Costs related not only to the cover crop, its planting and termination but also related to human costs for additional time and labor to manage the crop. The survey respondents also repeated the same perceived benefits of reduced soil erosion and improved soil health or quality as designated by increased soil organic matter. Soil health was also the number one benefit identified in the 2016-2017 SARE-CTIC annual report (CTIC, 2017).

Myers and Watts (2015) also summarized data from the 2014-2015 SARE-CTIC survey which not only included cover crop users but also farmers who never used cover crops. These surveys were not random but were directed to capture the full spectrum of cover crop usage across the different management systems. The top reason for adoption was improved soil organic matter followed by reduced erosion and reduced compaction. Non-adopters cited time and labor burdens as the number one reason for not considering cover crop addition. The non-adopters did not want to take the time to identify the best suited cover crop(s) for their operation. Cost associated with cover crops for many was considered too high. Myer and Watts (2015) also identified ag retailers as a potential technical resource for those inexperienced with cover crops.

Roesch-McNally et al. (2018) used focus groups of IA farmers comprised of 29 individuals who all experience with cover crops except two. Twenty-six of the 29 were planning on utilizing cover crops the following season. The majority were corn-soybean operations, half of which had livestock. The participants described overcoming barriers and dispelling perceptions related to cover crop use by using a holistic approach to cover crops management including changes to nutrient application and to equipment. Those considering themselves successful at cover crop management work closely with technical expertise available across the different farmer networks. However, without expansion of financial incentives or farmer desire to increase diversity in their operation, expansion of cover crop use will continue to grow at a slow pace.

Overcoming farmer reluctance or risk aversion to cover crop adoption may require additional research addressing their perceived concerns which ranged from cover crop potential to transfer diseases to the cash crop (Bakker et al., 2016, 2017; Dunbar et al., 2016; Archarya et al., 2017; Schenck et al., 2017), potential for cash crop yield penalties (Kaspar and Bakker, 2015; Panjota et al., 2015; Bakker et al., 2016; Basche et al., 2016a; Miguez, 2016; Patel et al., 2016; Acharya et al., 2017), reduced water and NO_3-N availability to the cash crop (Bakker et al., 2016; Carlisle, 2016; Svoma and Gantzer, 2016), increasing complexity at fall harvest and spring planting compounded by the unpredictable nature of the growing season (Carlisle, 2016; Svoma and Gantzer, 2016; Acharya et al., 2017), lack of shorter season but complementary cash crop and/or cover crop variety availability (Carlisle, 2016; Miguez, 2016), costs associated with adding cover crops (Acharya et al., 2017) and lack of expertise or ready access to expertise along with limited equipment accessibility (Carlisle, 2016).

Some of these concerns are addressed in more recent research which focused on the host potential of cereal cover crops for corn pathogens (Bakker et al., 2016), on the assessment of the microbial populations associated with dying cover crops (Bakker et al., 2017), and on the potential for increased insect damage to corn following a cereal cover crop (Dunbar et al., 2016), all of which are contributing factors for yield reduction in the following cash crop. Using the Koch's Postulates as the basis for their experiments, Bakker et al. (2016) evaluated the potential for the cash cereal crop, corn, following a cover cereal crop, winter rye, to increase disease risk in corn. In this study Bakker et al. (2016) looked for the pathogens, *Fusarium graminearum* (source of corn seed rots and seedling blights), *F. oxyspurum* (stalk rot pathogen), and *Pythium sylvaticum* and *P. torulosum* (seedling damp-off pathogens). The study concluded there is a potential for the winter rye roots to host corn pathogens because of higher pathogen populations in the corn following rye cover crops compared to the control treatment after winter fallow. Bakker et al. (2016) noted however greater pathogen population densities do not necessarily translate to increased risk for the corn crop for adverse yield impacts due to the complexity of genetic and environment interactions. Management practices such as increasing the time between cover crop termination and cash crop germination and those that protect the germinating seed and seedling from disease risks associated with cool, wet springs (i.e. seed treatments, planting at appropriate soil temperatures, avoiding planting into wet soils, etc.) can mitigate these potential hazards to the cash crop. Bakker et al. (2017) used polymerase chain reaction (PCR) to identify the potential fungal pathogens residing on winter rye roots three days, two weeks, and one month after herbicide termination. Samples were collected from treatments with and with cover crop from a corn-soybean rotation study which was located on the ISU Research Farm in Boone County, IA. Bakker et al. (2017) identified *P. volutum*, a common pathogen for turfgrasses and a previously undescribed Pythium species and used laboratory assays to verify these two pathogens were capable of infecting corn seedlings. Management practices such as avoiding planting in wet and cold soils were once again suggested by Bakker et al. (2017) as an effective strategy to minimize disease risk. Spatial variation in pathogen populations were attributed to the differences in soil types and their water holding capacities across the fields. Schenck et al. (2017) also concluded there is increased risk for disease in corn seedlings after a rye cover crop in cool, wet conditions through a series of experiments in a controlled environment. This increased risk persisted even if a fungicide treatment was applied to the corn. Schenck et al. (2017) did find less negative impacts on corn after alternative cover crops such as hairy vetch (*Vicia villosa* Roth) or winter canola (*Brassica napus* L.). Farmers have indicated through focus groups they would like expanded choices in cover crop species selection (Basche and Roesch-McNally, 2017).

Delaying the time interval as long as possible between cover crop termination and cash crop planting is one of the most common recommendations to reduce yield drag for the cash crop in studies focused on corn following a rye cover crop. Acharya et al. (2017) concluded intervals shorter than 10 days between termination and planting increase the risk of yield losses due to seedling diseases and the resulting reduced corn emergence in a two-year study in the field and in a controlled environment. Using a 15-day interval between rye cover crop termination and corn planting in a corn-soybean rotation, yield was significantly greater in both tillage and no-tillage treatments in 2015 (Fawcett et al., 2015). More interesting, however, is in a separate cover crop study, corn yield differences between the treatments with and without cover crops were not significantly different even though the periods between termination and planting ranged from same day to 13 days (Appelgate et al., 2017).

Dunbar et al. (2016) examined the population size differences of early-season insect pests and injury to corn between corn with and without cover crops in ‘commercial fields.’ Because winter rye is a host to true armyworm (*Mythimna unipuncta* Hayworth), black cutworm (*Agrotisipsilon Hufnagel*), and common stalk borer (*Papeiperma nebris* Gvenee), these researchers hypothesized corn pest populations would increase and injury to corn would increase in corn following the cover crop. Weekly sampling was performed starting in the middle of April through eighth leaf collar stage during 2014 and 2015. Of the three pests, true armyworm populations were significantly higher in the corn with the rye cover crop versus corn without the cover crop. The higher populations also corresponded to increased injury to the corn. Neither black cutworm nor common stalk borer populations were impacted by the presence of the cover crop. As with the pathogen studies, Dunbar et al. (2016) suggested increasing the awareness of true armyworm potential risk would help the farmer implement pest management strategies to mitigate the risk.

Competition for limited water availability is one of the more common concerns raised by farmers when considering the addition of cover crops to their operation. Svoma and Gantzer (2016) used 33 years of temperature and precipitation records, along with modeling of soil moisture holding capacity and evapotranspiration across the Upper Midwest to address concerns related to cover crop termination and cover crop potential to reduce the moisture availability to the subsequent cash crop. Because IA soils have relatively high water holding capacity compared to majority of the corn growing region along with the typically cool wet springs, the model predicted there is little possibility of low moisture availability to the cash crop even with late cover crop termination. However, Svoma and Gantzer (2016) noted the advantage due to current soil and climate in IA in terms of moisture availability may change with increasing spring temperatures.

No amount of research to mitigate the risks noted above will overcome farmer reluctance to add cover crops to their management system if the potential for yield reductions are not mitigated. Corn yield reductions in a typical corn-soybean rotation with cover crop ranged from approximately 6% (Panjota et al., 2015) to as high as 34% (Martinez-Feria et al., 2016a) when compared to the same rotation with no cover crop. However, over the six years evaluated in the Martinez et al. (2016a) study, the overall average yield drag was 6%. As cover crop biomass increased, yield drag for the subsequent corn crop was greater (Panjota et al., 2015). Soybean yield was not negatively impacted by the addition of a cover crop (Panjota et al., 2016; Martinez-Feria et al., 2016a). In Patel et al. (2016), research was initiated to develop best management practices for successful cover crop addition, i.e. minimizing corn yield drag. Four IA research farm sites which were historically managed with a corn-soybean rotation, rye cover crop, and no-tillage were utilized in this study. Corn yield comparisons were made between tillage (spring disk/field cultivate) with and without the cover crop and with and without starter N fertilization (30 lb N/acre as urea side-dressed two inches from and below the seed at planting). Even though the overall average yield decrease was 2% for the corn with cover crops across all the sites for the two years evaluated, tillage with the N side-dress produced the greatest yields with and without cover crops. These results suggest adding the N side-dress at planting could eliminate the potential yield drag (Patel et al., 2016).

Practical Considerations and Economics of Cover Crop Implementation

Cover crop choices

Winter rye is often recommended as the cover crop best suited for IA due to its rapid growth even under the cooler conditions frequently experienced in the fall in IA (Martinez-Feria et al., 2016a; Schenck et al., 2017), winter hardiness, and the amount of biomass generated prior to spring termination (Acharya, et al., 2017; Appelgate et al., 2017; Schenck et al., 2017). The extensive root system of winter rye provides another benefit by helping to hold the soil in place which can reduce soil loss due to erosion (Mine et al., 2017). Farmers, however, are interested in alternative cover crop species due to the concerns mentioned previously, i.e. the potential to transfer disease from the dying cereal cover crop to corn seedlings, the potential for the cover crop to harbor insect pests of corn, and the potential for yield drag due to continuous cereal cropping. More recently, researchers have investigated the use of winter canola, meadow fescue (*Festuca pratensis* Huds.), sheep fescue (*Festuca ovina* L.), Canada bluegrass (*Poa compressa* L.), fowl bluegrass (*Poa palustris* L.), colonial bentgrass (*Agrostis capillaris* L.), hairy vetch (*Vicia villosa* Roth), winter triticale (x *Triticosecale*), camelina *(Camelina sativa*), turnip (*Brassica rapa*), spring barley (*Hordeum vulgare*), and spring oats (*Avena satia* L.) (Flynn et al., 2013; Appelgate and Lenssen, 2016; Licht et al., 2016; Martinez-Feria et al., 2016b; Appelgate et al., 2017; Schenck et al., 2017), the use of different winter rye, winter triticale, and winter wheat cultivars (Kaspar and Bakker, 2015), and canola cultivars (Appelgate et al., 2017). Also tested were double cover crop mixtures of rye with canola, camelina or hairy vetch; triticale with camelina or hairy vetch; or triple cover mixtures of rye or triticale with camelina and hairy vetch (Appelgate et al., 2017); or hairy vetch, oats and radish (Licht et al., 2016) before corn in a corn-soybean rotation. In the study by Martinez-Feria et al. (2016), winter canola did not consistently overwinter particularly when there was no snow cover to protect the crop during the extreme temperatures in two winters. Even though the indicator of a hardy canola stand, fifth-leaf stage based on growing degree days, was achieved for both years before winter onset, canola performance as a cover crop was too inconsistent. However, Skelnar (2018) had excellent overwintering of two winter canola cultivars in one year as a cover crop. Flynn et al. (2013) found meadow fescue, fowl bluegrass, sheep fescue, colonial bentgrass, and Canada bluegrass met their criteria for cover crop performance, i.e. percent ground coverage in the fall and spring in the strip-tillage area and interrow. Yield reductions associated with these alternative cover crops ranged from approximately 25% in 2008 and 2009 for alpine bluegrass and meadow fescue, respectively, to 60% grain yield reduction for Canada bluegrass in 2010 to approximately 90% yield reduction for bentgrass in 2008. Unfortunately, Flynn et al. (2013) identified a negative correlation between good spring cover crop performance and corn yields the following growing season. Even then, the researchers described what they considered to be the 'ideal' perennial ground cover: one which is short in stature, forms clumps, can tolerate shade and greens later in the spring, and one which will only minimally compete with corn for resources (Flynn et al., 2013). Despite issues with cover crop establishment due to late planting, poor overwintering, and shortened growing seasons, Appelgate et al. (2017) found that canola cultivars, spring barley, and spring oat were not viable cover crop options for IA due to winterkill. Turnip and hairy vetch did not produce sufficient biomass in the fall, winterkilled and were therefore not good options for IA. Triticale cover crop and camelina cover crop produced approximately half of spring above-ground biomass as the rye cover crop alone or in mixtures with rye cover crops. For the same reasons mentioned above, none of the cover crops including rye alone and rye mixtures met performance expectations in the spring; consequently, there was little to no impact on the subsequent corn crop yields (Appelgate et al., 2017). Kaspar and Bakker (2015) found the performance varied among cultivars of rye, triticale, and wheat cover crops and their impact on corn yields over four growing seasons (2006 to 2009). There were no significant differences for corn yield among the seven winter rye cultivars, two winter triticale cultivars, or three winter wheat cultivars in 2008 and 2009. There were no significant differences between four and five of seven wheat cultivars in 2006 and 2007, respectively, in one of the two triticale cultivars in 2007, and one of the three wheat cultivars but the not the same one in 2006 and 2007. Kaspar and Bakker (2015) have recommended additional research with more cultivars across more locations and with cover crop selection and breeding.

Finally, two ISU research studies looked further into the potential benefits of using cover crop mixtures. In the first, Appelgate and Lenssen (2015), evaluated several possible measures of cover crop performance: above ground biomass, C and N accumulation, soil NO_3 concentrations, soil P, soil potassium, weed density and population distributions, and soil water. The barley, oat, and the canola cultivars did not survive the winter; turnip and hairy vetch were significantly impacted by winter conditions. They did find, however, that rye mixtures, which were rye with canola, rye with camelina, rye with hairy vetch, and rye with camelina and hairy vetch, delivered the same cover crop performance in terms of biomass, C and N accumulation as rye alone (Appelgate and Lenssen, 2015). Licht et al. (2016) found no significant differences in corn yields with either oats alone or the cover crop mixture of hairy vetch, oats, and radish.

Economics of cover crops

One of the most common reasons for farmers to not include cover crops is due to the additional resource demands and costs (Myers and Watts, 2015; Carlisle, 2016; Acharya et al., 2017; CTIC, 2017; Cruz et al., 2018). Perspectives for best use of conservation dollars for water quality projects include addition of cover crops (Roley et al., 2016; Christianson et al., 2018). However, addition of cover crops over many decades without consideration of the cropping system was projected as least cost effective compared to the addition of wetlands or two-stage ditches to both the farmer as well as for allocating conservation funds. Cover crops compared to the other two conservation practices have the least impact on farmer crop management systems (Roley et al., 2016). Partial budget analyses and/or case studies also found that the addition of cover crops often resulted in negative returns and required additional management time (De Haan et al. 2017; Mine et al., 2017; Plastina et al., 2018a, 2018b;). Farmers did see increased revenues from reduced erosion remediation costs and conservation dollars. In one study, a farmer noted that the cover crops provided weed suppression which translated to lower herbicide costs. Farmers with livestock were also able to see increased revenues due to lower investment in feed when the cover crops were used as forage or for grazing. Farmers also noted they received a rental contract from conservation-minded landowners with the promise of including cover crops on landowner fields. Farmers may also need to invest in new or upgrades to existing equipment either for planting into the residue or for planting the cover crop (Plastina et al., 2018a). Plastina et al. (2018b) performed a partial budget analyses based on survey responses for farm operations that plant cash crop rotations both with and without cover crops. In this study Plastina et al. (2018b) identified seed costs, planting costs, termination costs. These costs were only included in the partial budget analyses if the no cover crop fields were treated differently than the cover crop fields. Assessments were made also to determine if there were changes from the addition of cover crops to costs associated with cash crop seed and planting, fertilizer (both artificial and organic), pest control, soil testing, soil erosion remediation, and cash rent (Plastina et al., 2018b). Mine et al. (2017) limited the partial budget analyses to differences in termination methods, farmer years of experience with cover crops, and cover crop planting methods. Unless cover crops are used for livestock grazing or forage, cover crops were added as a loss to crop management system (Plastina et al., 2018b). In the case study partial budget, the farmer also experienced negative revenue from the addition of cover crops to selected fields in his northeast IA farm operation but the benefits to his fields were not easily translated into dollar values and therefore not captured in the partial budget (Mine et al., 2017). He noted improvements to soil health, water infiltration and drainage, soil compaction, weed and disease control although not quantifiable for the partial budget (Mine et al., 2017). He pointed out farmers who are considering the addition of cover crops must clearly identify their motivation for doing so as well as be willing to learn from others and to experiment with what works best on their fields. Cover crops are not a short-term commitment (Mine et al., 2017).

Economics are a key reason why retailers and CCA have or have not added cover crop seed and/or technical expertise to their list of products and services. While a majority of CCA and retailers surveyed have consulted on cover crop selection, planting services, nutrient management, termination services, and on-farm field trials, most have only seen very minimal impact on revenue. Even so, adding or expanding cover crop seed selections and consultation services are opportunities to expand and grow their businesses. Like farmers, the CCA and retailers feel that more information and research is needed to develop regional best management practices for cover crops including the expansion of farmer-to-farmer educational and farmer-to-conservation professional collaboration. Ongoing economic research at the retail level, i.e. what could cover crops do for a retailer, is also needed (Cruz et al., 2018).

CHAPTER 5

CONCLUSIONS

Committing to cover crops is a long-term process requiring continual improvements to production management systems for the farmer, the landowner, and farmer support networks both locally and regionally through the different non-government (NGO), industry, and government organizations. Challenging the agriculture industry to enter the conversation about cover crops with programs such as Stine Seed Sustainability Cover Crop Initiative could go a long way to increasing cover crop adoption. The agriculture industry currently does not see cover crops as an enhancement to their business models. While these companies have sustainability 'initiatives,' their programs do not address the vital role cover crops can play in the long-term health of customer soils which can translate into increased profitability for their customers. Public institutions need to reach out to the private sector with innovative ways showing how cover crops can benefit their businesses. Educating farmer support networks that a 'clean' field might not be a healthy field in the long term will be key. Practical Farmers of Iowa (PFI) is an excellent resource for information on cover crops. What is not clear, however, is whether PFI is able to reach beyond their organic and niche market farmer clientele to farmers who historically have embraced the model promoted by the mainstream agriculture industry. Creating a core group of CCAs that understand the needs of their clients as well as the learning curves needed to add cover crops to an operation, i.e. a systemic approach, may be needed to expand the resources promoting cover crop use.

Public institutions such as ISU should continue to encourage farmers to implement cover crops by experimenting with a small portion of their farming operation as a practical way to expand cover crop usage. Working with the farmer to try cover crops in less than desirable areas, which historically have had low yields, should be a part of any program to expand cover crop use. Considering the tight margins in the current farm economy, any financial assistance with the costs associated with cover crops is needed as an incentive to try cover crops. Based on typical inputs and outputs for partial budget analyses and the high potential for yield drag with a cereal grain cover crop before corn, cost models must be developed for soil quality improvements, reductions in soil erosion, and reductions in nutrient losses to gain the full potential value of adding cover crops to farmer management systems. Assigning costs associated with soil loss and reduced soil health may be a powerful tool to predict potential revenue losses with decreased productivity or increased input requirements and costs to maintain profitability. Values should be determined for savings cover crop adopters have experienced by reduced need for soil erosion remediation.

While the modeling exercises are helpful for policy decision makers, they are not useful on a practical level. More research should be directed to practical questions that farmers are asking: management best practices for their farming areas, cover crop seed breeding for specific regions, optimizing cover crop growth curves, maturity with cash crop growth curves. Local best management practices should encompass subjects such as planting cover crops, planting cash crop into residues, pest control (weeds, insects, and diseases), termination methods, soil quality metrics for tracking soil health improvements, minimizing adverse yield impacts on subsequent cash crops, and reducing revenue losses in operations without livestock. Fostering farmer-to-farmer education opportunities should include the pros and cons, challenges of moving from conventional to no-tillage system, and conventional to organic systems. The days are gone when the farming community should remain divided between the agricultural industry model and the organic model for row crops. Why? The current rate of adoption of cover crops in IA means it will take almost 100 years to reach the goals set by the INRS. Even now, it may be too late to save Iowa's soil and water resources.

Table 2: Experimental locations, rotation, cover crop species and study years

Authors[a,b]	IA Sites	Rotation	Cover Crop(s)	Data Source Years
Acharya et al., 2017	ISU Boyd Farm - Boone County	Rye after soybean in the fall followed by corn planted in the spring	Elbon rye	2013-2014 2014-2015
Appelgate and Lenssen, 2016	Ames	Rye after soybean in the fall followed by corn planted in the spring	Winter rye	2013-2014
	Lewis			2013-2014 2014-2015
	Boone			2014-2015
	Sutherland			2014-2015
Appelgate et al., 2017	Ames	Rye after soybean in the fall followed by corn planted in the spring	Winter rye Winter triticale Winter camelina Spring barley Spring oat Turnip Hairy vetch Two-way mixtures Three-way mixtures	2013-2014
	Lewis (different site each season)			2013-2014 2014-2015
	Boone			2014-2015
	Sutherland			2014-2015
Bakker et al., 2016	Controlled-environment Five sites near Ames	Corn-soybean	Elbon rye	2014-2015
Bakker et al., 2017	ISU Research Farm - Boone	Rye after soybean in the fall	Elbon rye	2013-2014
Basche et al., 2016a (modeling) APSIM	Kelly Tile Experiment - Boone County	Corn Soybean	winter rye	2001-2014
Basche et.al., 2016b	Boone County	Corn Soybean	Winter rye	2008-2014
Bonner et al., 2014 (modeling) LEAF	IA	Corn-soybean Corn-corn-soybean	Winter rye	2008-2010
Daigh et al., 2014a	Agricultural Drainage Water Research Site ISU AEARF – Boone County	Corn Soybean	Rye	2011-2012

Table 2: Experimental locations, rotation, cover crop species and study years (continued)

Authors	IA Sites	Rotation	Cover Crop(s)	Data Source Years
Daigh et al., 2014b	Comparison of Biofuel Cropping Systems (COBS) - Ames	Corn-soybean Soybean-corn Continuous corn Continuous corn-winter rye cover crop Reconstructed mixed prairie	Winter rye	2009-2012
De Haan et al., 2017	Sioux Center	Continuous corn/cereal rye		2009-2013
		Smooth brome grass Orchard grass		
		Oat /alfalfa Alfalfa Corn		
		Oat/red clover Corn		
		Soybean /winter wheat) Winter wheat/red clover Corn/cereal rye		
Dunbar et al., 2016	IA	Non *(*Bt) corn	Rye	2014-2015
Fawcett et al., 2017	Buena Vista County Sioux County	Soybean-corn	Rye Triticale	2014-2015
Flynn et al., 2013	Sorenson Research Station - Boone County	Corn	35 grass and legume species	2008-2010
Gillette et al., 2018 (modeling) RZWQM	Boone County	Corn-soybean	Cereal rye	1999-2010
Hartzler and Anderson, 2015	Greenhouse		Cereal rye Oat Hairy vetch Lentil Radish	
Iqbal et al., 2015	AEARF – Boone County	Corn Soybean	Winter rye	2011-2013

Table 2: Experimental locations, rotation, cover crop species and study years (continued)

Authors	IA Sites	Rotation	Cover Crop(s)	Data Source Years
Kaspar and Bakker, 2015	AEARF – Boone County	Corn Soybean	7 winter rye cultivars 2 winter triticale cultivars 3 winter wheat cultivars	2006-2009
Licht et al., 2016	ISU Research and Demonstration Sites: Sutherland, Kanawha, Nashua, Lewis, McNay, Crawfordsville	Corn Soybean	Before corn: oats or mix of hairy vetch, oats and radish Before soybean: rye or mix of rapeseed, rye and radish	2014-2015
Malone et al., 2014 (modeling) RZWQM	Boone County	Corn Soybean	Winter rye	2000-2005
Malone et al., 2017 (modeling) HERMES & RZWQM	Boone County	Corn Soybean	Winter rye	2000-2005
Malone et al., 2018 (modeling) RZWQM	Central IA	Corn Soybean	Winter rye	2001-2010
Martinez-Feria et al., 2016a (modeling) APSIM	COBS - Boone	Continuous corn	Rye	2009-2014
Martinez-Feria et al., 2018 (modeling) APSIM	ISU Research and Demonstration Farms: Kelley (two sites) Nashua	Corn Soybean	Rye	2008-2016
Martinez-Feria et al., 2016b	AEARF – Boone County	Soybean	Winter canola	2012-2014
Meng et al., 2016	COBS – Boone County	Continuous Corn Corn-soybean rotation Multispecies prairie	Rye	2013

Table 2: Experimental locations, rotation, cover crop species and study years (continued)

Authors	IA Sites	Rotation	Cover Crop(s)	Data Source Years
Mine et al., 2017	Moore Farm – Howard County	Corn Soybean	Annual rye Cereal rye	2014-2016
Moore et al., 2014	ISU Boyd Farm – Boone County	Corn Corn silage Soybean	Rye	2001-2011
Mitchell et al., 2013	AEARF – Boone County	Corn Soybean	Winter rye	2011
Nair and Lawson, 2015	Muscatine Island Research Farm - Fruitland	Sweet corn	Yellow mustard Oilseed radish Cereal rye	2014
Nair et al., 2015	Horticulture Research Station - Ames		Crimson clover Red clover Yellow sweetclover	2014
Panjota et al., 2015	AEARF - Ames Southeast Research and Demonstration Farm – Crawfordsville Southwest Armstrong Memorial Research and Demonstration Farm – Lewis Northeast Research and Demonstration Farm - Nashua	Corn Soybean	Rye	2009-2011
Panjota et al., 2016	AEARF – Ames Southeast Research and Demonstration Farm – Crawfordsville Armstrong Memorial Research and Demonstration Farm – Lewis Northeast Research and Demonstration Farm – Nashua	Corn Soybean	Rye	2010-2011
Parkin et al., 2016	Central IA	Corn Soybean	Winter rye	2004-2013

Table 2: Experimental locations, rotation, cover crop species and study years (continued)

Authors	IA Sites	Rotation	Cover Crop(s)	Data Source Years
Patel et al., 2015	AEARF - Boone	Corn Soybean	Winter cereal rye	2014-2015
Patel et al., 2016	Southeast Research and Demonstration Farm – Crawfordsville Southwest Armstrong Memorial Research and Demonstration Farm – Lewis Northeast Research and Demonstration Farm - Nashua Northwest Research and Demonstration Farm, Sutherland	Corn Soybean	Rye	2014-2015
Pederson et al., 2014	Nashua	Corn Soybean	Rye	2008-2012
Pederson et al., 2016	ISU Northeast Research and Demonstration Farm - Nashua	Corn Soybean	Rye	2008-2015
Schenck et al., 2017	Controlled environments	Corn	Rye Winter canola Hairy vetch	
Skelnar, 2018	Ames	Corn silage-soybean	Winter rye ‘Spooner’ Canola ‘Sitro’ Camelina ‘Bison’ Turnip ‘Purple top turnip’	2012-2014
Woli et al., 2016	Armstrong Memorial Research and Demonstration Farm – Lewis	Corn Soybean	Rye	2010
Xuan et al., 2017 (modeling) DRAINMOD-N II	Iowa Agricultural Drainage and Water Quality Research and Demonstration Site – Pocahontas County	Corn Soybean	Rye	2005-2009

[a] Refer to the individual publications for details regarding the individual field sites, historical and in-study cultural practices, and/or fertilizer applications.
[b] Unless otherwise indicated controls were same rotations, same tillage practices without cover crop between cash crop rotations; controls used for controlled environments were no cover crop.

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APPENDIX A

ABBREVIATIONS

ACPF	Agricultural Conservation Planning Framework
AEARF	Agricultural Engineering and Agronomy Research Farm
APSIM	Agricultural Production Systems sIMulator
ArcGIS	Arc geographic information system
Bt	*Bacillus thuriengiensis*
C	carbon
CCA	Certified Crop Advisor
COBS	Comparison of Biofuel Systems
CTIC	Conservation Technology Information Center
DNR	Iowa Department of Natural Resources
IA	Iowa
IDALS	Iowa Department of Agriculture and Land Stewardship
INRS	Iowa Nutrient Reduction Strategy
ISU	Iowa State University
KNO_3	potassium nitrate
LEAF	Landscape Environmental Assessment Framework
LLR	the natural log of N_2O flux with a cover crop compared to systems without cover crop
mM	millimolar
N	nitrogen

N_2O	nitrous oxide
NO_3-N	nitrate-nitrogen
NUE	nitrogen use efficiency
NUE_{crop}	nitrogen cycling in terms of the crop
NUE_{soil}	nitrogen cycling in terms of the soil
P	phosphorus
PCR	polymerase chain reaction
RCB	Randomized complete block
RZWQM	Root Zone Water Quality Model
SARE	Sustainable Agriculture Research & Education
sNUE	system NUE
SWAT	Soil and Water Assessment Tool
UAN	urea ammonium nitrate
US EPA	United States Environmental Protection Agency
USDA-ARS	United States Department of Agriculture Agricultural Research Service
USDA-NRCS	USDA Natural Resources Conservation Service